Page proofs should be dispatched to:
Jose M. García-Ruiz
Instituto Pirenaico de Ecología
Campus de Aula Dei
Apartado 202
50080-Zaragoza
SPAIN
Telephone number: 34-976-716026
Fax: 34-976-716019
e-mail: humberto@ipe.csic.es

STRATIFIED SCREE IN THE CENTRAL SPANISH PYRENEES: PALEOENVIRONMENTAL IMPLICATIONS

J.M. García-Ruiz (1), B. Valero-Garcés (1), P. González-Sampériz (1), A. Lorente (1), C. Martí-Bono (1), S. Beguería (1) and L. Edwards(2)

(1) Instituto Pirenaico de Ecología, CSIC, Campus de Aula Dei, Apartado 202, 50080-Zaragoza, Spain.
(2) Dept. of Geology and Geophysics, University of Minnessota, Minneapolis, MN45045, USA.

Abstract

Sedimentological, geomorphological and palynological study of three stratified screes from two environments in the Central Spanish Pyrenees allow reconstruction of climate and vegetational change since the Last Glacial Maximum (LGM). In both localities (at 700 and 1000 m a.s.l.) the deposits show a similar stratigraphy: i) a basal stratified scree, in one case fossilized by speleothems; ii) a paleosol, with abundant charcoal and evidence of human activity; and iii) a massive coarse scree. The stratified scree developed during the Glacial Maximum and Late Glacial. A humid period during the early Holocene was characterized by speleothem formation and carbonate cementation in some screes. Forest fires around 3300 BP were widespread in the Pyrenees and were probably related to human impact. Recent scree reactivation due to an increase in clast supply is limited to cold stages during the late Holocene.

Resumé

L'étude sédimentologique, géomorphologique et palynologique de troix dépôts de pente stratifiés localisés dans deux environments des Pyrénées centrales espagnoles permet de reconstituer des changements du climat et de la végétation depuis le Dernier Maximum Glaciaire. Dans les deux sites les dépôts présentent la même stratigraphie: i) un éboulis stratifié basal parfois fossilisé par des spéleothèmes; ii) un paléosol, avec de nombreux charbons de bois et des preuves d'activités humaines; et iii) un éboulis grossier massif. Les éboulis stratifiés se sont développés pendant le Dernier Maximum Glaciaire et le Tardiglaciaire. Une période humide au début de l'Holocène est caracterisé par la formation de spéleothèmes et de cimentations carbonatées dans quelques éboulis. Les feux de forêt autour de 3300 ans BP semblent être très repandus dans les Pyrenées et ils sont en rapport, probablement, avec l'impact humain. La dernière réactivation de l'éboulisation due à l'accroissement de la fourniture de débris est limitée aux épisodes froids de la fin de l'Holocène.

Key-words: Stratified screes, Paleosol, Pollen analysis, Glacial maximum, Oldest Dryas, Central Spanish Pyrenees.

Introduction

Relict and active stratified screes are typical geomorphic features in mountain areas. They occur at the foot of cliffs and are composed of alternating matrix-supported beds and openwork layers (Tricart and Cailleux, 1967; Francou, 1988). The main hypotheses of their origin include debris flow activity, creep and sheet wash erosion (Tricart, 1956; Lliboutry, 1961; Boardman, 1978; Van Steijn *et al.,* 1984). Recently, detailed sedimentological studies (Nemec and Kazanci, 1999) attribute their genesis to alternating activity of cohesive debris flows, grain flows, sheet wash processes and slushflows (Harris and Prick, 2000). Bertran *et* *al*. (1992 and 1995) and Van Steijn *et al*. (1995) confirm the existence of several models that explain the development of stratified slope deposits: stone-banked solifluction sheets and lobes (Francou, 1988), solifluction lobes (Bertran *et al*., 1993), dry grain flows and frost-coated clast flows (Hétu et al., 1994), debris flows (Van Steijn, 1988; Bertran and Texier, 1994), and nivo-eolian transport (Hétu, 1991).

Stratified screes is widely considered indicative of the lower limit of the periglacial belt (Tricart and Cailleux, 1967; Peña, 1998). In the Pyrenees they are found everywhere, from lowlands close to the Ebro Depression (below 500 m a.s.l.), to high elevations up to 3000 m a.s.l. (Peña *et al*., 1998). Some clearly correspond to relict morphoclimatic conditions and reflect colder periods of the Pleistocene. In such cases they are located at relatively low altitudes, on the lower parts of hillslopes, occasionally resting upon low fluvial terraces.

Screes located at the highest altitudes (over 2200 m a.s.l.) are active, as a consequence of frequent freeze-thaw cycles (Del Barrio *et al*., 1990; García-Ruiz *et al*., 1990; Chueca *et al*., 1994). They occur in glacial cirques, and adjacent to tors and cliffs. They are close to the upper divides on all aspects, though preferably in shady exposures (García-Ruiz, 1989; Serrano, 1998). In general, plant colonization is totally absent.

At middle and low altitudes, most of the Pyrenean screes can be considered as colluvium, not exclusively related to cold environments (García-Ruiz and Ruiz-Budría, 1977; Serrano, 1998). However, some show structures typical of stratified screes (*éboulis ordonnés*: Tricart and Cailleux, 1967), and thought characteristic of periglacial conditions (Solé Sugranyes, 1973; Serrat, 1977; González-Martín, 1986; Chueca *et al*., 1994; Peña *et al*., 1998; Serrano, 1998; Martí-Bono and González, 1977).

This note describes three stratified scree deposits located in the Pyrenees and Pre-Pyrenees, and assesses their potential as paleoenvironmental indicators.

The study area

Stratified screes were studied in: (1) the Bentué de Rasal Valley (Central Pre-Pyrenees) and (2) the Devotas Canyon, in the upper Cinca Valley (Central Pyrenees) (Fig.1. Table 1).

The Bentué de Rasal Valley is located at the northern side of the Outer Sierras, an overthrusting anticline composed of Cretaceous and Eocene limestones and marls. Hillslopes are steep, with almost vertical sandy limestone cliffs that supply clasts and blocks to small screes, little covered by vegetation. One scree, located on the norh-northeastern slope of Peiró Mt. has been used recently for gravel extraction, allowing in part the study of its inner structure. This deposit is at 1000 m a.s.l. Here, average annual precipitation is ≈800 mm per year and mean annual air temperature is ≈11.5ºC.

The Devotas Canyon has been carved within Paleogene sandy limestones, and constitutes a N-S reach of the river valley immediately after its confluence with the Cinqueta tributary. The bottom of the gorge is at 690-730 m a.s.l. Martí Bono and García-Ruiz (1993) and García-Ruiz and Martí-Bono (1994) note no geomorphological or sedimentological evidence to support the passage of glacial ice through the Devotas Canyon, contrary to Penck's (1883) point of view. There are neither morainic rests in the Canyon, nor morainic blocks incorporated to slope deposits.

Two exposures were studied in the Devotas Canyon, both on the right side of the valley: i) Devotas 1, located at the exit of the Canyon, in a trench opened by the construction of a road tunnel, at 700 m a.s.l. and ii) Devotas 2, located in the central stretch of the Canyon, corresponding to a stratified scree mined for gravel, at 710 m a.s.l. Both exposures occur at the foot of east-northeast-facing slopes. Here, average annual precipitation is ≈1250 mm and mean annual air temperature is ≈12ºC.

Methods

Field descriptions of the deposits included sedimentary structures and textures (grain size distribution), fabric of selected openwork layers, and geomorphological mapping in relation to other Quaternary deposits (terraces and moraines).

Palynological studies were performed on fine-grained samples from the Bentué de Rasal and Devotas 2 deposits. Four samples were subject to extraction and concentration of palynomorphes, following the classical chemical method (Delcourt *et al.,* 1959; Girard, 1975; Dupré, 1992). Pollen concentrations were calculated with the incorporation of *Lycopodium* tablets (Stockmarr, 1971). Two pollen samples were used for AMS 14C dating (Table 2). In Bentué de Rasal small rests of charcoal were taken for 14C dating. In Devotas 1, two speleotheme samples were collected and in Devotas 2, a sample of carbonate cement, partially encrusting the deposit, was also taken. Both were subject to U/Th series dating (Table 2).

Results

The Bentué de Rasal deposit

This deposit is composed of 4 units (A-D) (Fig. 2):

A) A basal unit, with a visible thickness of 4 m, consists of crudely stratified alternating coarse and fine layers, up to 20 cm thick each. The gradient of the layers is 26º. Coarse layers show an open-work (clast supported) structure, with a heterogeneous clast size distribution and many clasts over 10 cm in the *a* axis. The fine layers are composed of clasts up to 5 cm long, with a matrix-supported texture. The contact between layers is blurred, with many irregularities. In a frontal exposure the layers show little continuity, being affected by short-wave sinuosities. The unit is interpreted as an irregularly stratified scree.

B) A 40-cm thick, dark-brown unit, composed of clasts up to 15 cm long within a sandy matrix (30 %) containing charcoal remains. This unit is interpreted as a paleosol.

C) The paleosol is overlain by a 50-cm thick unit composed of loose blocks, without any fine matrix. Most clasts have an *a* axis over 20 cm in length. This unit is interpreted as a massive openwork scree.

D) The exposure is topped by a 50-cm thick unit of loose, small clasts (median size, 3 cm). This unit shows a higher gradient (38º) than the underlying units. It is interpreted as a massive, openwork scree developed by single-particle rockfall.

Pollen from the basal unit (Bentué 1) provided an age of 13,770± 100 years 14C BP (AZ 33221) and charcoal from the unit B was dated as 3,340±70 years 14C BP (UBAR-447).

The paleosol shows an arboreal pollen proportion of around 35%, while the stratified deposit has a proportion of around 60% of the total (Fig. 3). The pollen spectrum shows that during deposition of the stratified scree the most representative species was *Juniperus*, a colonizing, pioneering plant of bare soils. Some pine (7%) and birch (2%) is also indicated but graminea and the other herbaceous plants are scarce. The pollen spectrum from the paleosol suggests a Mediterranean landscape dominated by thermophylous and heliophylous species. *Juniperus*, *Pinus* and *Quercus* t. *ilex-coccifera* are found within a herbaceous cover dominated by *Poaceae* and *Chenopodiaceae* together with *Brassicaceae, Lamiaceae, Centaurea, Urticaceae, Compositae, Helianthemum* and *Geraniaceae*. *Asphodelus* reveals the occurrence of periodic fires (Jalut, 1991) and the presence of eggshells of parasites characteristic of domestic animals (*Trichuris* and *Ascaris*) suggests livestock activity (Bouchet, 1994). The pollen spectrum is interpreted as a deforested Mediterranean landscape. The presence of fire and livestock indicators suggest an anthropogenic origin for this deforestation.

4.2. The Devotas Canyon deposits

The two stratigraphic sections described in the Devotas Canyon (Devotas 1 and 2) have more than 20 m in thickness. At both sites the deposit consists of a stratified scree composed of alternating layers of open, clast-supported structure, and matrix-rich, sandy layers (Fig. 4). In Devotas 1 (Fig. 5) stratification is more regular, with more continuous openwork layers, separated by rectilinear planes, and with frequent vertical grading, corresponding to an A-type stratified deposits (Bertran *et al*., 1995). Clast size distribution of the openwork layers shows great differences between layers. The gradient of the deposit is 22º.

The Devotas 1 deposit revealed a small cave located at the foot of the rockwall against which the scree had accumulated. Some clasts from the cliff had accumulated in the cave, in an ordered stratified sequence. This unit is fossilized by calcitic speleothem deposits that cover the bottom of the cave (Fig. 5). The stalagmitic unit suggests vertical water flow, while the laminated speleothem suggests flooding in the cave. The U/Th ages obtained indicate that the stalagmite formed between 10,910 ± 55 U/Th years BP (base of the column) (DV1-Univ. Minnessota), and 9,040±100 U/Th years BP (the upper part) (DV2-Univ. Minnessota).

Both in Devotas 1 and 2 the upper parts of the stratified screes have been encrusted by carbonated cement, particularly at the boundaries between layers of different porosity. This cement shows a massive structure in the matrix-rich layers, while it has a spongy appearance in those of open work structure.

The spongy cement of the stratified scree could not be dated due to its very low Uranium-237 and very high Thorium-232 concentration. However, the age of pollen from the lower stratified scree in Devotas 2 is 22,800 ± 200 14C years BP (AZ 35865) (Table 2). The arboreal pollen percentage in the scree (Devotas 2) hardly reaches 20% of the total, and more than half corresponds to pine, a great pollen-producing tree. In the paleosol the A.P. percentage is higher, around 50%. The presence of abundant charcoal indicates the occurrence of fires that, however, did not cause an important reduction of the tree cover.

5. Discussion and conclusions

The main geomorphological stages in scree evolution can be interpreted from the geomorphological and palynological data:

i) The stratified screes formed during two main periods: the coldest stage of the Upper Pleistocene and the Late Glacial (especially the Oldest Dryas).

Of the three deposits studied, Devotas 1 seems to have been mainly developed by means of stone-banked solifluction lobes (Francou, 1988; Bertan *et al*., 1995): there is clear stratification of openwork and matrix-rich layers, vertical clast-size classification in the openwork layers, and lateral continuity of the beds. In the case of Devotas 2, discontinuities in the layers and an almost total absence of vertical grading suggests the role of debris flow and maybe frost-coated clast flow (Van Steijn *et al*., 1988 and 1995; Nieuwenhuizen and Van Steijn, 1990). Some, well developed stratified layers point to the occasional occurrence of solifluction. Finally, the Bentué de Rasal scree appears mainly due to debris flows.

Since the height of the rockwall is greater in Devotas 2 than in Devotas 1 (Table 1), this may explain the greater clast supply in Devotas 2 and the higher gradient of the slope deposit. These factors would encourage the triggering of debris flows in Devotas 2 (e.g. Innes, 1983), alternating with some solifluction. As Van Steijn *et al*. (1995) state, the occurrence of stone-banked solifluction lobes seems to be characteristic of periglacial conditions (needle ice, frost heave and sorting), while debris flows occur in a wider range of environmental conditions (Innes, 1983).

In the case of the Bentué de Rasal, a cold climate is also thought responsible for the scree deposits. However, the facies prevailing do not necessarily support a periglacial climate: the deposit has been formed by debris flows and single particle rockfall, under conditions of low temperature and precipitation, as the pollen spectrum reveals. These conditions are typical of the Late Glacial, but probably were not severe in the Pre-Pyrenees.

ii) Speleothemes formed in the time period between the Youngest Dryas and the Pre-Boreal in the Devotas Canyon, coinciding with an amelioration of climate and greater humidity.

iii) Soil development occurred during the Holocene, both in the Devotas Canyon and Bentué de Rasal. In the case of Devotas 2, the scree was previously eroded, since the soil rests unconformably upon the stratified deposit.

iv) Forest fires occurred in the Late Holocene, around 3,300 years B.P.

v) The recent supply of clasts from the rockwalls towards the screes, initially very coarse and finally very fine, have an ambiguous climatic meaning, not necessarily linked to a cold spell. In the case of Bentué de Rasal (and maybe also in the Devotas Canyon) fire could have facilitated sediment transfer from the cliffs to the screes, until then restricted by the presence of trees. This stage might possibly correspond to the end of the Subboreal period. The finer clasts could be related to the Little Ice Age. In any case, this final stage is dominated by single particle rockfalls, without any redistribution over the talus. Its gradient and depth increase toward the rockwall.

The presence of charcoal-rich levels and domestic livestock parasits around 3,300 B.P. must be associated with human activity. This is consistent with other palynological and archaeological data from the Central Spanish Pyrenees. Thus, Montserrat (1992) identifies a detritic layer with ashes, dated in 3980±50 B.P., followed by a quick forest recovering. Andrés (1992) and Marsan and Utrilla (1996) described deforestation processes caused by fires linked to the expansion of domestic livestock (Megalitic culture). The deposits described in this paper show that the effect of cattle farming are much higher in the Pre-Pyrenees than in the high Pyrenean valleys, due probably to a more typical Mediterranean environment in the Pre-Pyrenees. In the case of the paleosol developed on top of both screes the lower A.P. rate in Bentué de Rasal is probably due to the greater intensity and/or frequency of fires related to human activity. In fact, in Bentué de Rasal, an open, sub-Mediterranean forest dominated, with thermophyllous and heliophyllous herbaceous species. By contrast, in the Devotas Canyon the mixed montane forest implies that a cool wet environment, similar to today, was present.

Acknowledgements

This paper has been realized with the support of the Project "Isotope sedimentology of 40Ka time-series from Iberian sites as a test of abrupt humid-subhumid switching within the Mediterranean climate zone" (EAR 941-8657), funded by the National Science Foundation of the United States of America, and Debrisfall assessment in mountain catchments for local end-users-DAMOCLES" (EVG1-1999-00027P), funded by the European Commission. The authors thank two anonymous referees for comments upon an earlier draft of the paper, and the Editor-in-Chief, Professor Hugh French, undertooke significant editorial modifications.

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FIGURE CAPTIONS

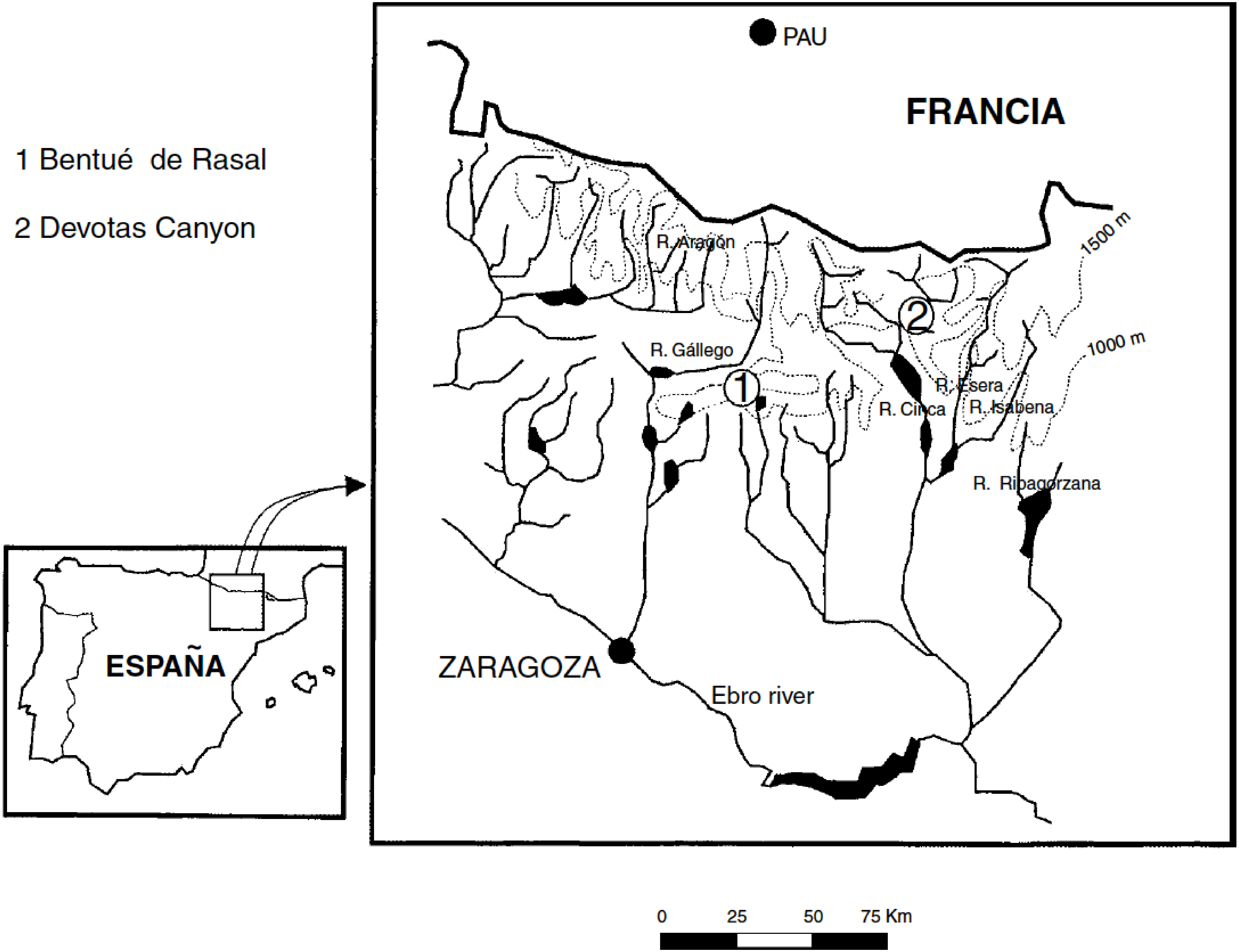
Fig.1. The study area with the location of the studied deposits.

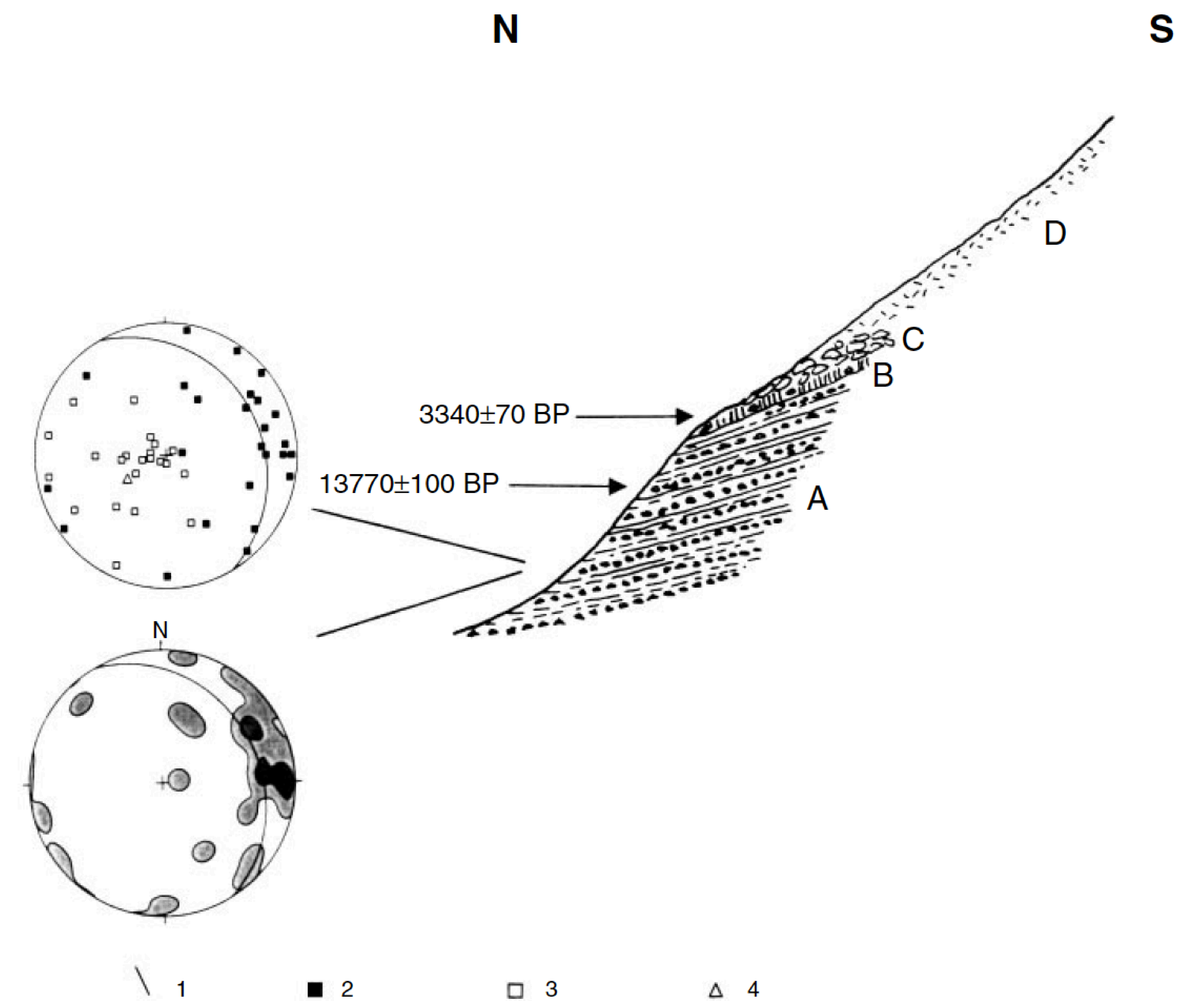
Fig. 2. The stratified scree of Bentué de Rasal and associated fabric (stereographic projection of the clast axes and density diagrammes). A: Stratified scree. B: Paleosol with clasts and ashes. C: Clasts and blocks in an open work structure. D: Semi-active, recent scree, with small clasts. 1: Stratification plane. 2: Orientation of the *a* axis. 3: Poles of the *a-b* planes. 4: Pole of the stratification plane.

Fig. 3. Pollen spectrum of the paleosol (1) and the stratified scree (2) of Bentué de Rasal.

Fig. 4: Stratigraphic column from Devotas 1 and associated fabrics (stereographic projection of the clast axes and density diagrammes). 1: Stratification plane. 2: Orientation of the *a* axis. 3: Poles of the *a-b* planes. 4: Pole of the stratification plane.

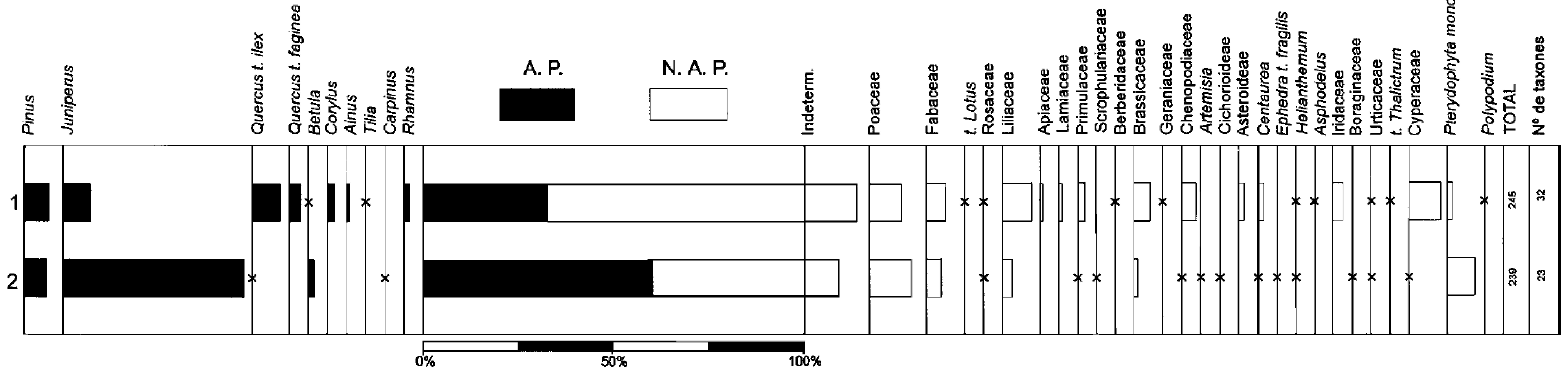
Fig.5. The stratified scree of Devotas 1, in the Devotas Canyon, Cinca Valley. 1: Paleosol. 2: Stalagmitic layer. 3: Scree with carbonatic, diffuse cement. 4: Stratified scree. 5: Limestone blocks. 6: Fluvioglacial terrace (15 m).

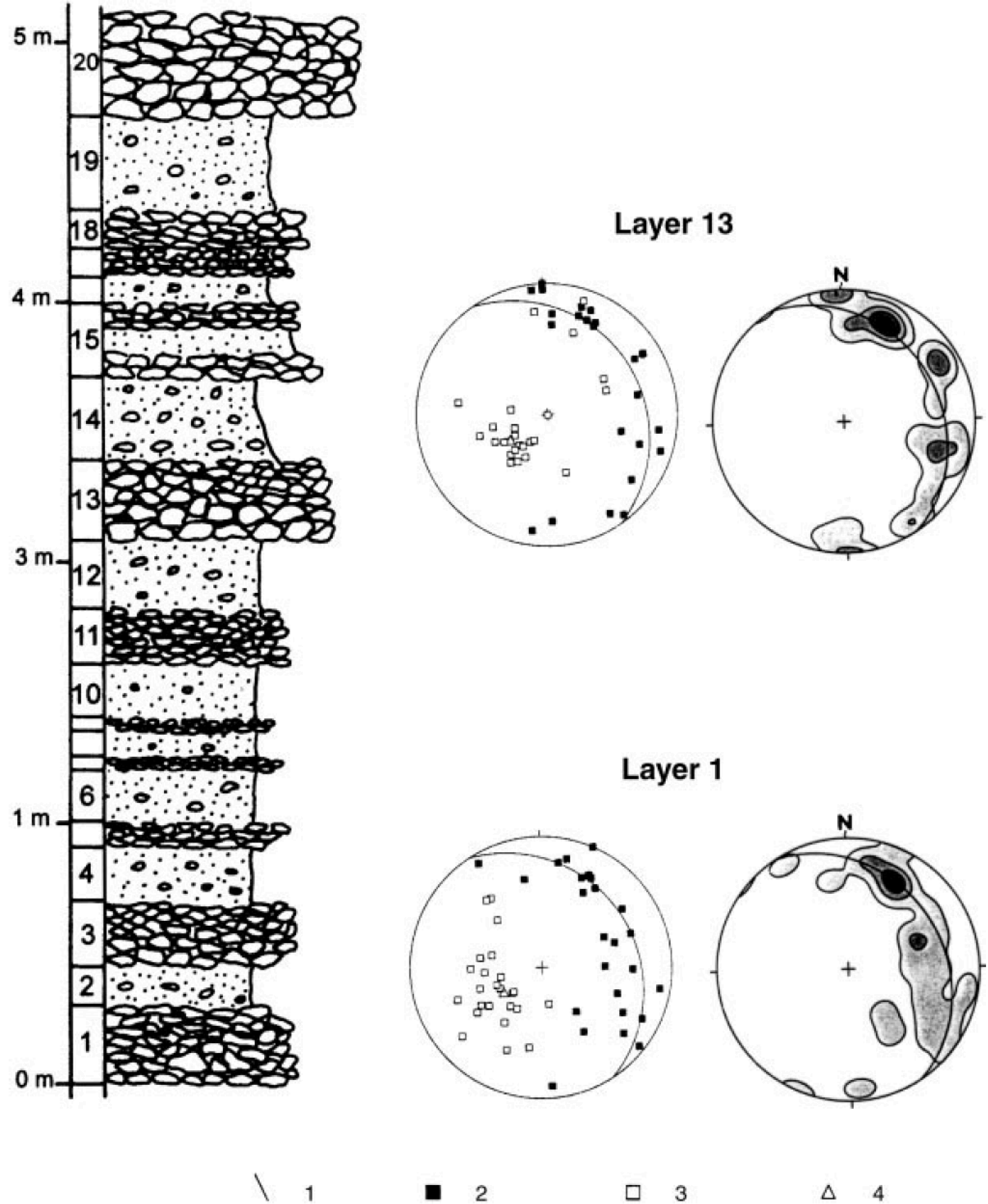

1 Bentué de Rasal
2 Devotas Canyon
PAU
FRANCIA
R. Aragón
R. Gállego
1500 m
1000 m
R. Esera
R. Cinca
R. Isabena
R. Ribagorzana
ZARAGOZA
Ebro river
ESPAÑA
0
25
50
75 Km



N
S
D
C
B
3340±70 BP
13770±100 BP
A
N
1
2
3
4

BENTUÉ DE RASAL




5 m
4 m
3 m
1 m
0 m
20
19
18
15
14
13
12
11
10
6
4
3
2
1
Layer 13
N
Layer 1
N
1
2
3
4

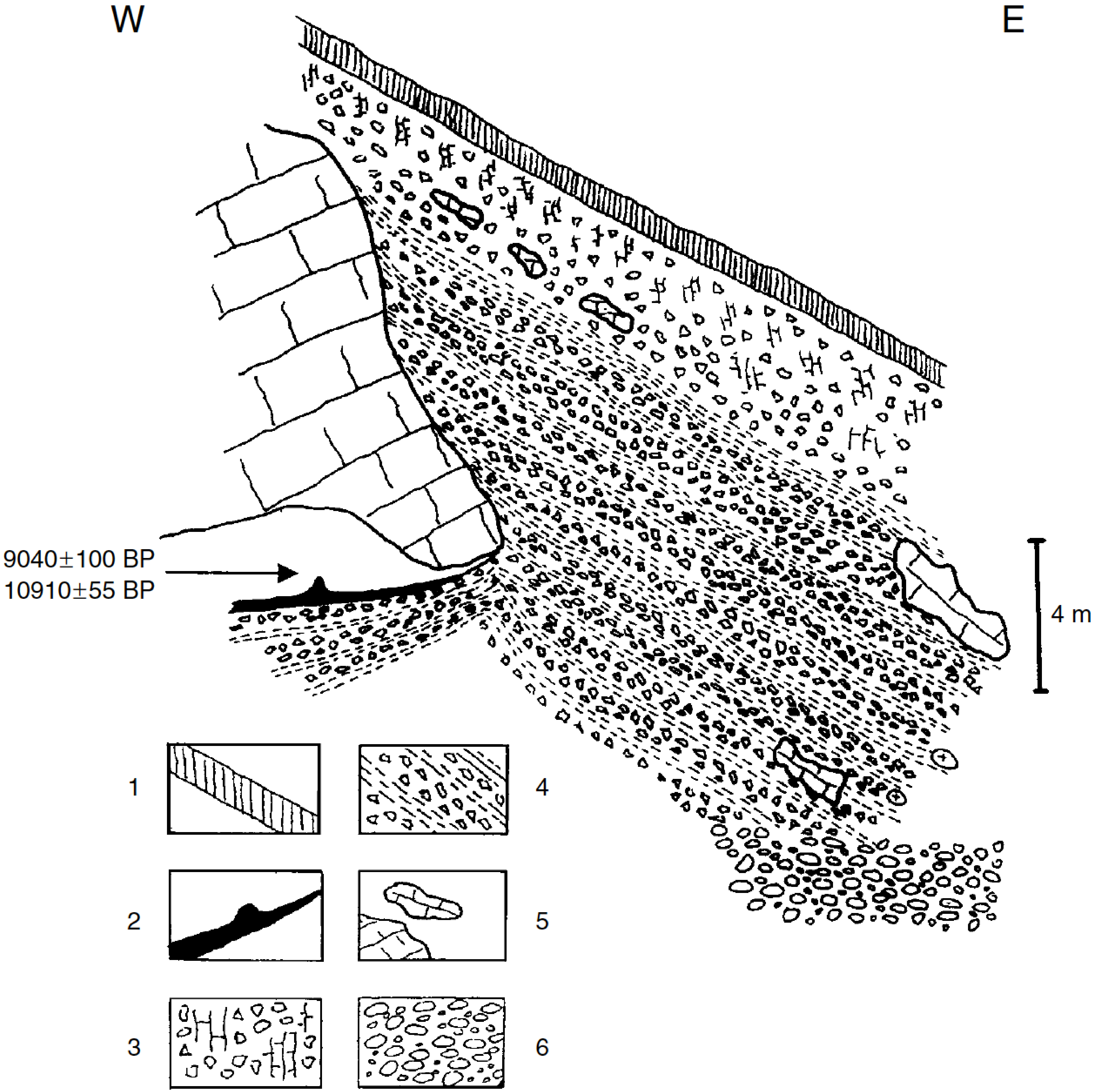

W
E
9040±100 BP
10910±55 BP
4 m
1
2
3
4
5
6

Table 1. Characteristics of sites studied in the Central Spanish Pyrenees

	Bentué De R.	Devotas 1	Devotas 2
Altitude (m)	1000	700	710
Mean ann. Temp. (º)	11.5	12	12
Annual precip. (mm)	800	1250	1250
Aspect	NNE	ENE	ENE
Mean slope angle (º)	26	22	28
Cliff height (m)	150	70	190
H_0/H_i ratio	0.25	0.4	0.25
Lithology	Limestone	Limestone	Limestone

Table 2. C_{14} and U/Th age determinations obtained from stratified scree deposits in the Spanish Pyrenees

Locality	Type of material	Level	Age (years BP)	Error	$d^{13}C$	Number of laboratory
Bentué de Rasal	Charcoal	Paleosol	3,340 (*) (14C)	± 70		UBAR-447 (Barcelona)
Bentué de Rasal	Pollen	Stratified scree	13,770 (*)(14C)	± 100	-23.5	AZ 33221 (Arizona)
Devotas Canyon (Devotas 2)	Pollen	Stratified scree	22,800 (*) (14C)	± 200	-28.3	AZ 35865 (Arizona)
Devotas Canyon (Devotas 1)	Speleothem (Lower stalagmite)	Stratified scree	10,910 (U/Th)	± 55		DV1 (Univ. Minnessota)
Devotas Canyon (Devotas 1)	Speleothem (Upper stalagmite)	Stratified scree	9,040 (U/Th)	± 100		DV2 (Univ. Minnessota)

(*) Calibrated